International Journal of Electronics, Communication & Instrumentation Engineering Research and Development (IJECIERD)
ISSN(P): 2249-684X; ISSN(E): 2249-7951
Vol. 4, Issue 3, Jun 2014, 105-110
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WAVEFORM OPTIMIZATION FOR IMPROVED TARGET VISIBILITY IN MEDIUM PRF RADAR

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ABSTRACT

Medium PRF radar systems were devised as a compromise between Low and High PRF systems and allow all-round measurements of both the range and Doppler of targets in high clutter environments to be made. This paper proposes a novel pulse repetition frequency (PRF) selection scheme in medium PRF pulsed-Doppler radars. The optimization is driven by the requirement not only to minimize the blind zone in the range and velocity space but also to ensure the full decodability of the true range and Doppler frequency.

KEYWORDS: Medium Pulse Repetition Frequency (PRF), Pulsed Doppler Radar, Blind Zone

INTRODUCTION

Radar, which stands for “Radio Detection and Ranging,” involves an electromagnetic sensor which is used to detect and locate targets and has a major role in modern weapon systems. The key features of radar are long-range detection capability and all weather functionality. Basically, radar propagates electromagnetic energy from an antenna to targets. The energy then reflects and scatters in various directions, some of which returns back to the radar antenna. This radar backscatter is often called an “echo.” After a process of amplification and signal progressing, presence of a target is detected by the radar together with potential descriptive information about the target. Medium PRF Doppler radar is a compromise design which is recognized as ambiguous both in the range and Doppler domains. The main advantage of medium PRF radar is that it has better performance than low PRF radars against closing targets and better performance than high PRF radars against tail-aspect targets. This feature makes medium PRF radars uniquely suitable where all aspect coverage is needed. The selection of pulse repetition frequencies has significance since the determination of the presence and the extent of ambiguity in both the range and Doppler domains depends on the selection.

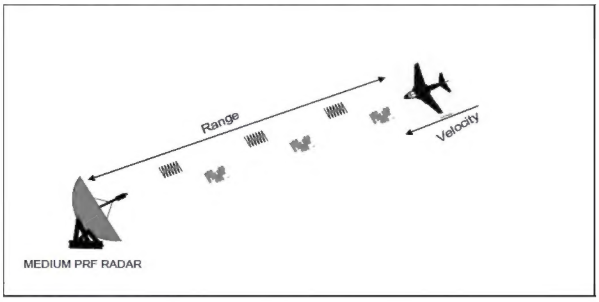

Figure 1: Medium PRF Radar and Targets

MEDIUM PRF OPERATION

Pulsed Doppler radars are effective to discriminate targets from clutter returns by using multiple pulses. The use of proper PRF is one of the most important issues affecting the performance of pulse Doppler radar. Radar systems can be classified into three types based on ambiguity of the interest range and doppler frequency. A low PRF system has unambiguous range of interest while the velocities of interest are ambiguous. A high PRF system experiences ambiguous range but unambiguous doppler interval. As a compromise solution to overcome the limitations of both a low and high PRF system, a medium PRF system induces the ambiguities in both the range and velocity but less than a low and high PRF. Therefore, the ambiguities of medium PRF system can be resolved by using multiple PRFs and it is one of the reasons that medium PRF systems are most widely used in pulsed Doppler radars. Although more PRFs improve the problem of ambiguities, the number of PRFs that can be used is limited by the illuminating time on target, which is decided by antenna rotation speed and azimuth beam width. Thus, it is important to choose the most suitable PRF set, just with the moderate number of PRFs. One of the methods which assess the suitability of a PRF set is to minimize the blind zone, which is adopted in our approach. In pulsed Doppler radar, strong clutter returns into the antenna main beam disturb the target detection. Thus, main beam clutter is discriminated from the target by FFT. Doppler processing and rejected by notch filters. Then, blind velocity in which no target can be detected repeats in the Doppler frequency domain at multiples of the PRF. On the other hand, due to the side lobe of the antenna, targets compete with side lobe clutter which is spread at all Doppler frequencies up to the platform velocity. The strongest return from directly below the platform repeats in the time domain at intervals of the pulse repetition interval (PRI). Moreover, the radar is blind during the time that pulses are being transmitted, which is called eclipsing.

PRF SET SELECTION

Because radar systems vary so much in their functions and the way they are implemented and because examples seem to speak so much better than general discussions, the remainder of this paper will address a specific example of PRF set selection.

Constraints

The first task in developing a medium PRF set for a pulse-doppler search mode is to define all of the constraints. Changing just one constraint can force the entire selection process to be redone, so considerable care should go into this task. The general trade-offs in defining constraints and the specific choices made for the example being presented are

- The spacing must be chosen for the samples of the received signal. This is the range bin size. This example will have range bins spaced 1.0 microsecond apart. (To correlate in range the detections from **3** PRFs and to keep a constant range bin size, each PRF must have an integer number of range bins per IPP. This limits the possible PRFs to a finite set of discrete frequencies. A PRF is equal to the inverse of the number of range bins per IPP times the bin spacing in seconds.
- The transmitted pulse width (no pulse compression) must be chosen. It must be long enough to provide sufficient energy for target detection. It must be short enough *to* provide adequate range resolution and to avoid exceeding the average duty cycle of the transmitter. The pulse width for this example will be the same as the range bin spacing, 1.0 microsecond.

- The total number of PRFs must be chosen. With too few PRFs the ability to deal with blind zones will be impaired. Depending on the average PRF and the antenna scan speed, with too many PRFs it may not be possible to transmit all of them during the time the antenna main lobe is on the target.
- A PRF set is constrained by the potential loss of range bins due to side lobe clutter and "eclipsing". Eclipsing affects the first few range bins of a pulse; when the radar is transmitting it cannot be receiving. The problem region caused by side lobe clutter is determined primarily by range bin spacing, radar altitude, antenna pattern, and aircraft velocity. For this example it will be assumed that the worst case is when the eclipsed and side lobe clutter range bins are contiguous and so, the first 10 range bins of each IPP for each PRF will be considered blind.

M/N DETECTION SCHEME

One of the methods which assess the suitability of a PRF set is to minimize the blind zone, which is adopted in our approach. In pulsed Doppler radar, strong clutter returns into the antenna main beam disturb the target detection.

Thus, main beam clutter is discriminated from the target by FFT Doppler processing and rejected by notch filters. Then, blind velocity in which no target can be detected repeats in the Doppler frequency domain at multiples of the PRF. On the other hand, due to the side lobe of the antenna, targets compete with side lobe clutter which is spread at all Doppler frequencies up to the platform velocity. The strongest return from directly below the platform repeats in the time domain at intervals of the pulse repetition interval (PRI). Moreover, the radar is blind during the time that pulses are being transmitted, which is called eclipsing. The eclipsing also repeats in the time at interval of PRI. Figure 1 shows typical blind zone map for a single PRI. On the other hand, because blind zones of each PRF appear at different range and doppler locations, PRF values can be selected to make interest region detectable for at least several PRFs and to satisfy unambiguity, simultaneously. A commonly used method is an M of N scheme. According to this scheme, a set of NPRFs is selected in order that a target can be detected in any interest range and velocity for at least M PRFs. Then, these M PRFs are also used to resolve the ambiguities. We adopt a 3 of 8 criterion as the most common and practical choice.

RESULTS AND DISCUSSIONS

The most common method of assessing the suitability of a PRF set is known as a blind zone map. It is a plot of all Doppler frequencies of interest against all ranges of interest, showing in its simplest form, all the areas of this range/Doppler space that are not covered by enough PRFs to detect the target reliably and are therefore said to be blind to it. Both Doppler frequency and range are effectively quantized in a real design resulting in a blind zone map that can be conveniently modelled as a matrix of cells The objective of this study was to minimize the total number of blind cells. Blind zone plots are a useful tool in assessing how well a PRF set will perform because they show trends that simple scoring cannot reveal. PRF sets that have made their way through the above screening process may have blind zone plots that exhibit the following problems; (1) several small blind zones close together creating what is, in effect, a large blind zone, (2) blind zones that are small in range but spread over many frequencies and (3) large areas where the PRF set is near-blind. Near blind areas create problems, especially at far ranges, since the probability of detection decreases with range. A blind zone plot with added near-blind regions is shown in figure for the designated "best" PRF set found. The blind range due to side lobe clutter and eclipsing is simulated by blinding a total of 11 cells at repetitions of the PRI in range (1 cell for eclipsing, 10 cells for side lobe clutter). The main clutter notch is simulated by blinding 3.4 kHz

(§25:5 m/s) at every repetition in frequency and corresponds to §17cells at multiples of each PRF. The simulation was performed for 1000 150 m range cells and 200 100Hz velocity cells giving a total region of 150 km and40 kHz (= 600m/s). The unavoidably blind regions in range and Doppler beginning at cell zero are not included in the calculation of the blind area.

Table 1: Summary of Radar Characteristics

Parameter	Value
Frequency	10 GHz
Wavelength	3 cm
Min PRF frequency	10.4 KHz
Max PRF frequency	20.0 KHz
Pulse width	1μS
Range bin size	150 m

Table 1 presents the important parameters considered for the target detection.

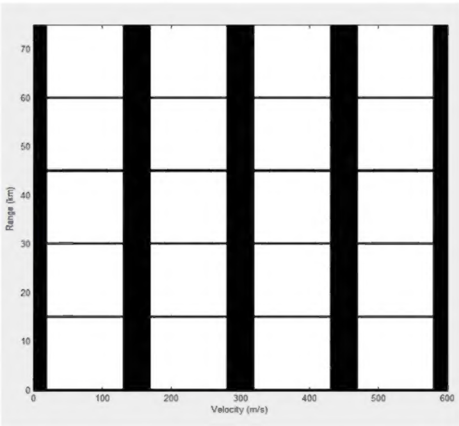

Figure 2: Blind Zone Map for PRI 100 μs

Most current medium-PRF search modes use a **3** of 8, double threshold detection scheme. To determine the true target range and velocity, detection is attempted in each of eight coherent dwells as the antenna scans the target. If threshold crossings are achieved in any three of the eight PRF switch resolve to the same range and velocity value, detection is declared and the target's range and velocity estimates are presented. Figure 2 shows the blind zone map for pulse repetition interval for PRI 100 μs

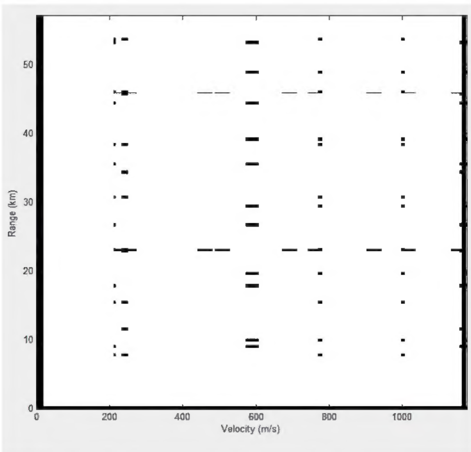

Figure 3: Blind Zone Map for Typical 2 of 4 Criterion

The white region indicates the visibility zone. Figure 3 shows the blind zone map for a 2 of 4 criterion. Which reduces the blind zone compared to the case in Figure 1. The corresponding PRIs are [51 μs, 59 μs, 65 μs and 76 μs].

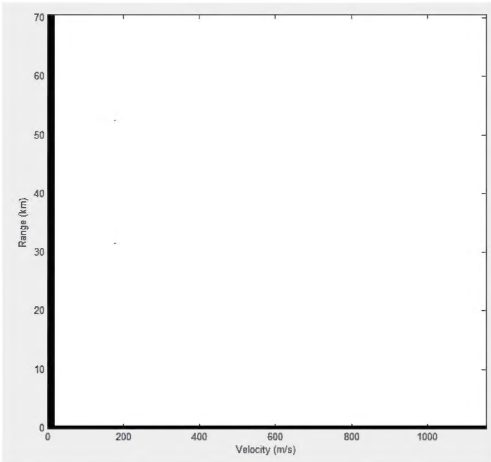

Figure 4: Blind Zone Map for Typical 3 of 8 Criterion

Figure 4 shows the blind zone map for a 3 of 8 criterion. which reduces the blind zone compared to the case in Figure 3. The corresponding PRIs are [52 μs, 58 μs, 64 μs, 70 μs, 76 μs, 82 μs, 88 μs and 94 μs]. The visibility has increased drastically and near 100% detection is possible with this scheme.

AREAS OF FURTHER PURSUIT

Since a major function of a PRF set is target detection, plots showing probability of detection as a function of range and doppler frequency might be a useful supplement to blind zone plots. Also, the selection process might be made more efficient by performing some scoring during execution of the evolutionary algorithm.

CONCLUSIONS

The probability of detection in the medium PRF search mode is affected by the PRF visibility The PRF set for a medium PRF coherent radar plays a crucial role in the system performance in look-down search situations. An exhaustive search for an optimum PRF set is expedited by a systematic approach of constraint definition and computer searches.

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